Understanding the effects of lower boundary variations on the IT System using GITM

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Outline

- **INTRODUCTION AND MOTIVATION**
- METHODOLOGY
- RESULTS
- QUESTIONS AND FUTURE STUDY PROPOSAL

Introduction

- The coupling between the lower and the upper atmosphere involves direct transport of chemical constituents, momentum flux and energy.
- Mesosphere and thermosphere dominated by very different physics - neutral vs plasma dynamics.
- Coupling mechanisms : Tides, Planetary waves, Gravity waves, Turbulence
- Difficult to understand because of complexity and lack of observations.

MOTIVATION

MSIS O/N2

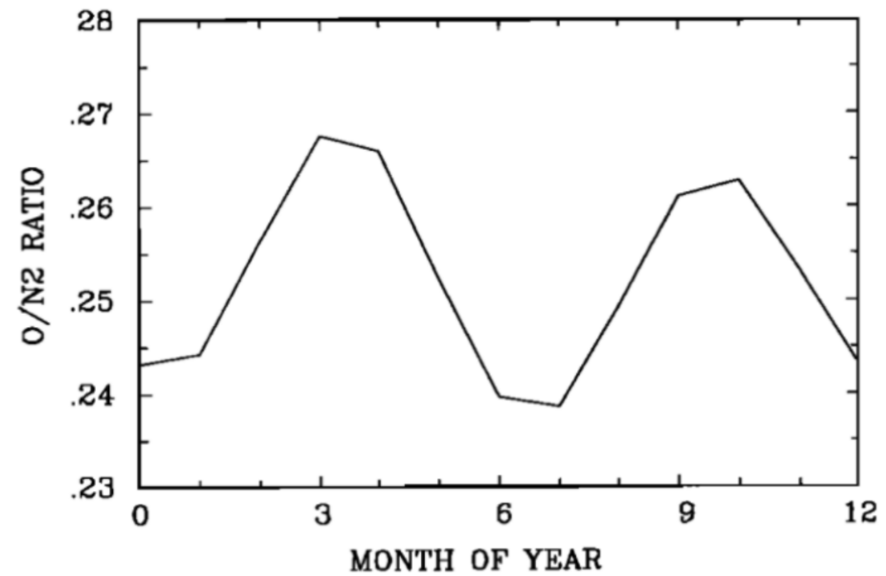
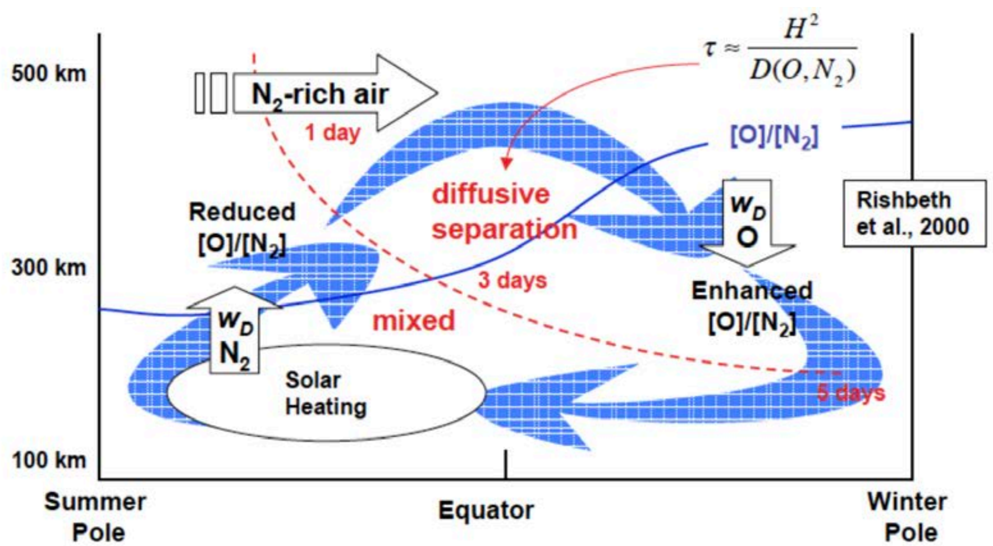
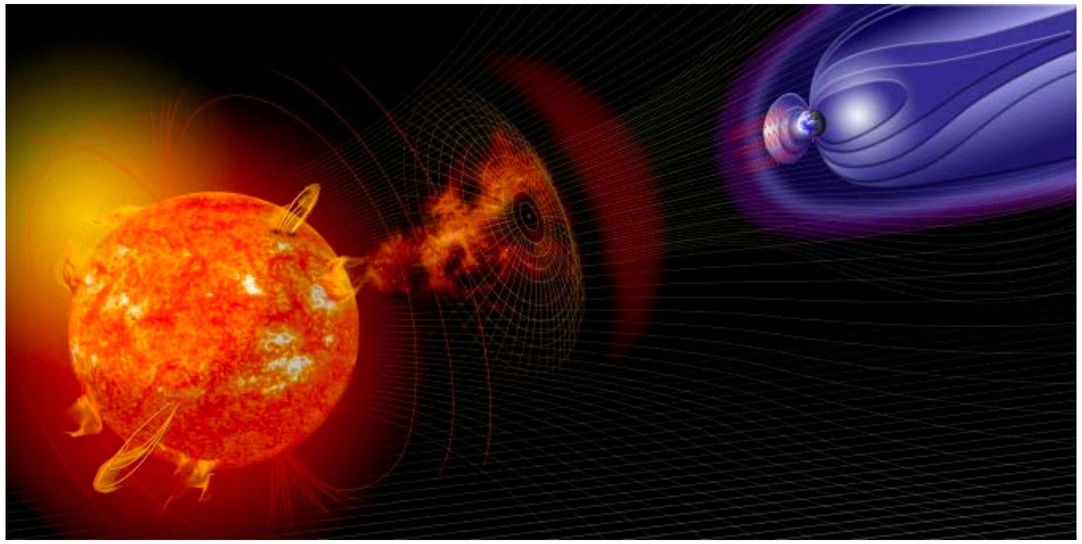


Figure 2. Variation of globally averaged O/N_2 at 120 km altitude as a function of month of year from the MSIS empirical thermospheric model [*Hedin*, 1987]. The *Ap* index is 5, and 10.7 cm index is 125.

Fuller Rowell, 1998

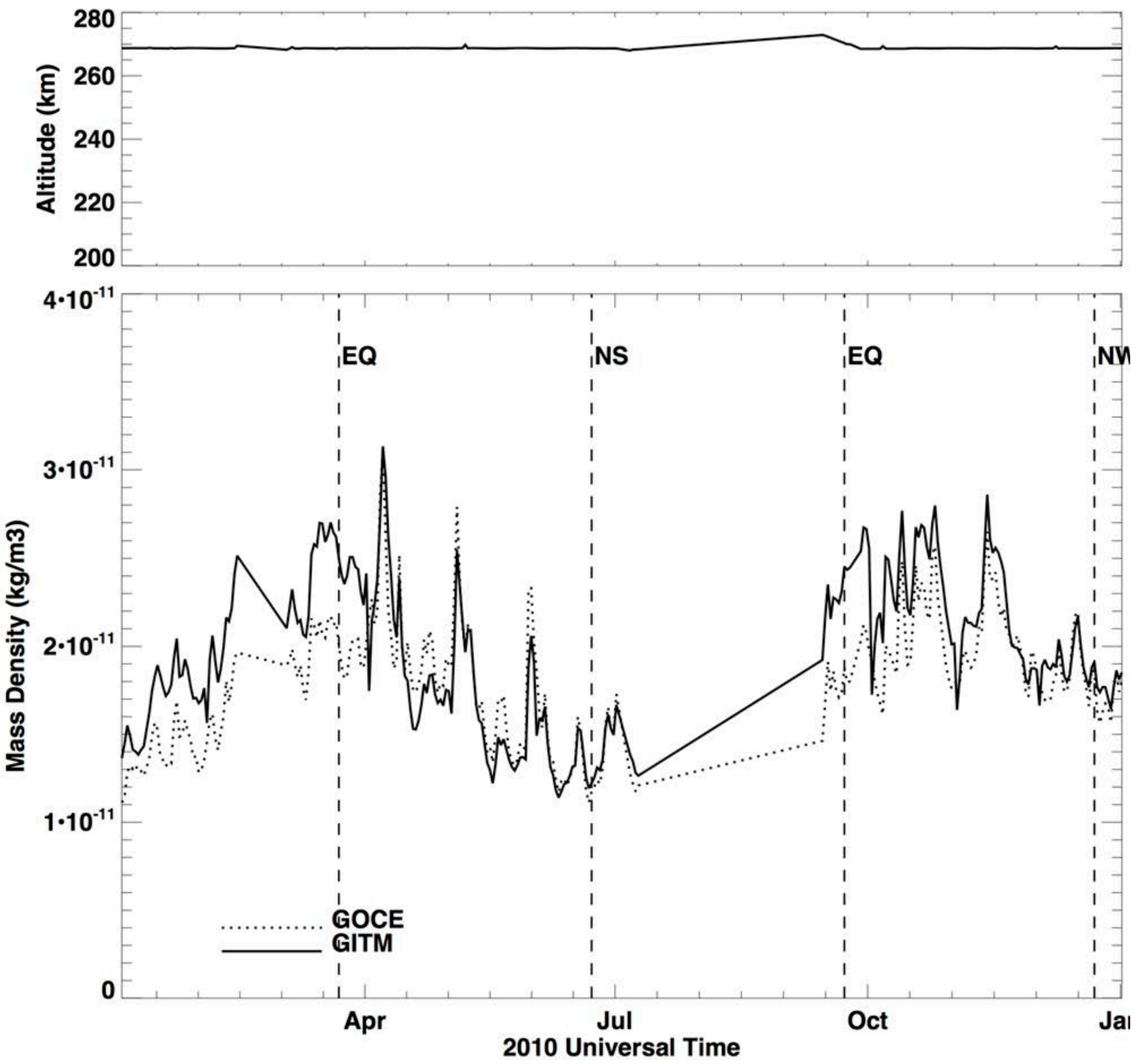
What is the reason for this seasonal and semi-annual variation ?

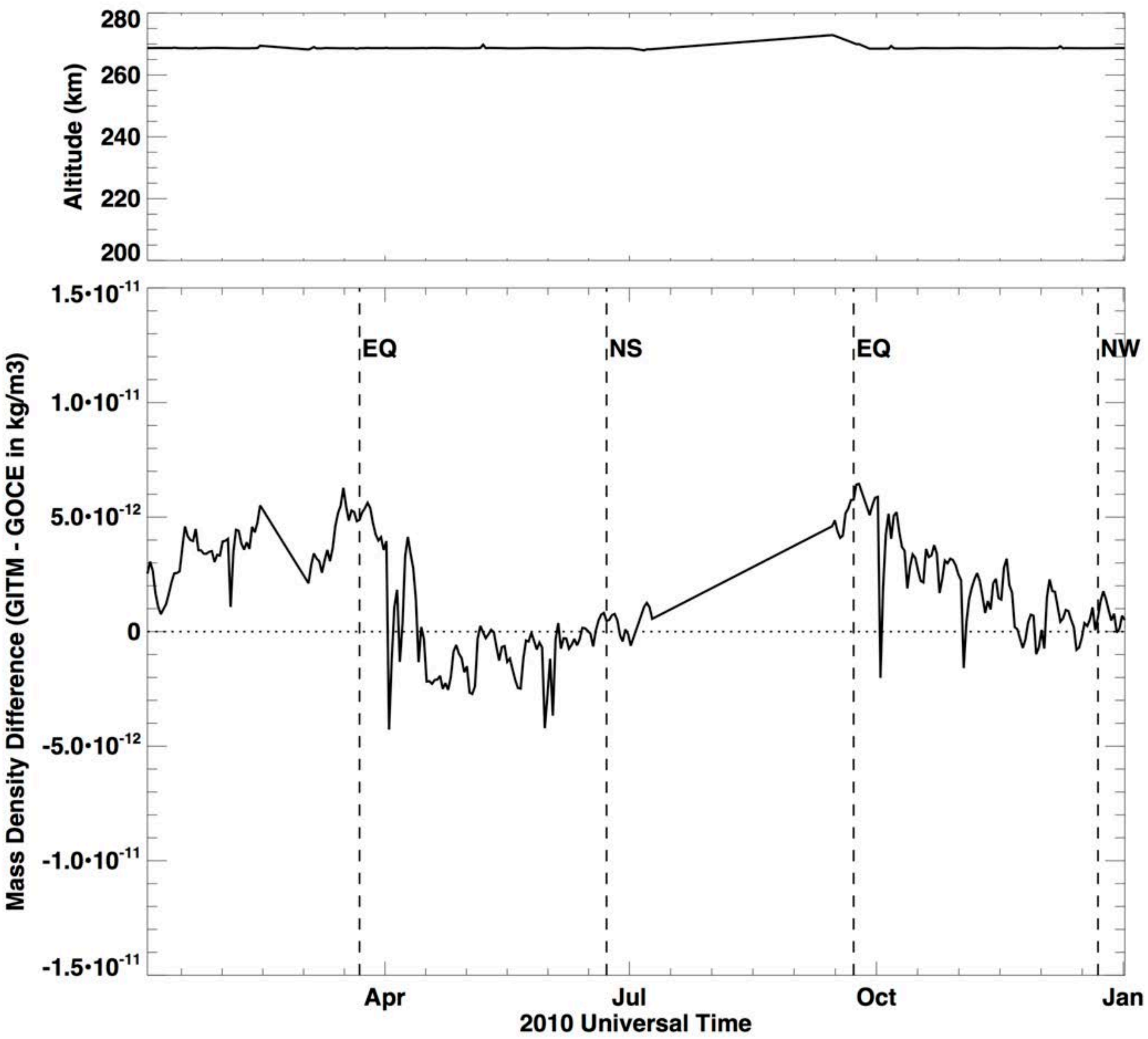




Mass Densities- GITM vs GOCE

2010





GITM vs TIE-GCM TEC for 2010

Perlongo et al., 2018

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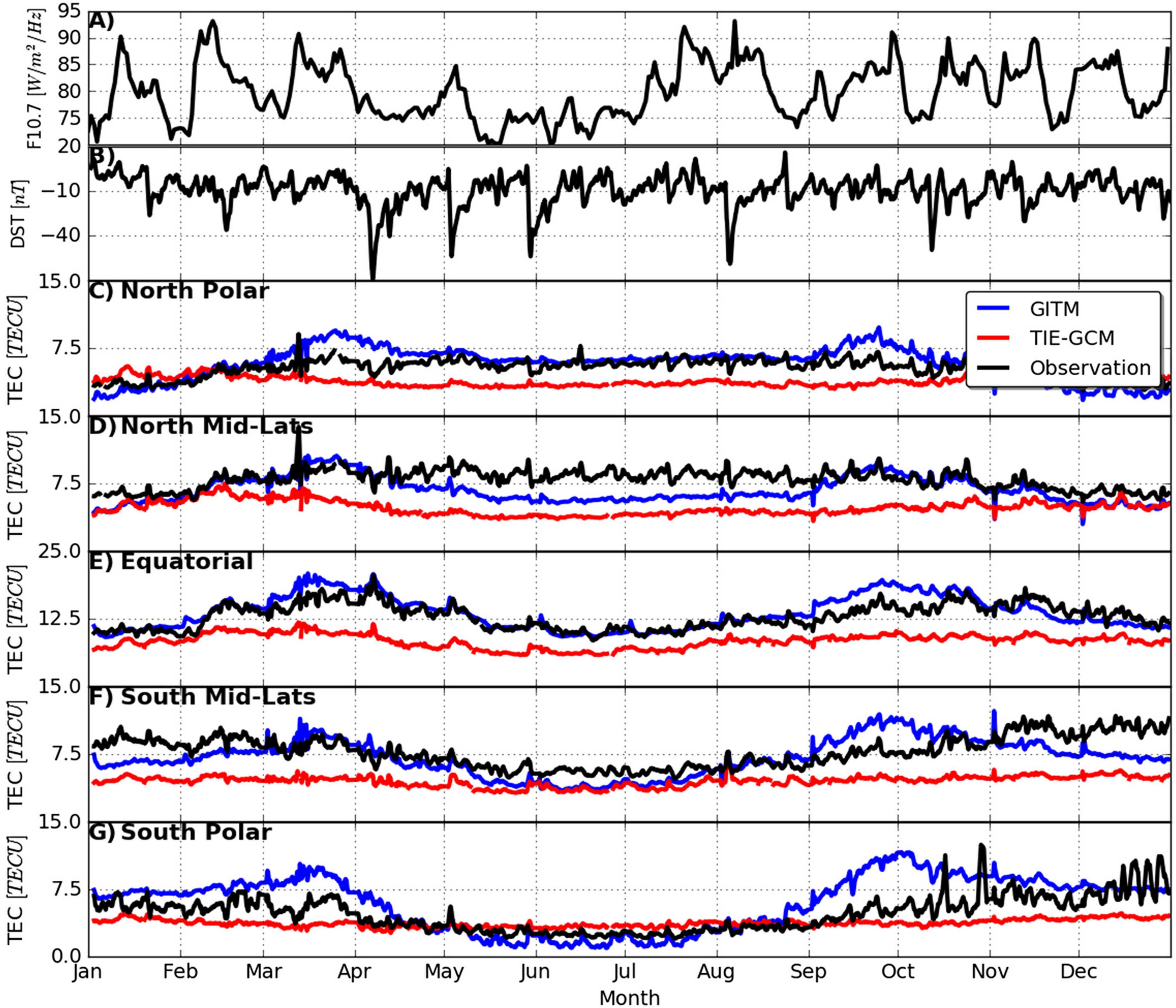


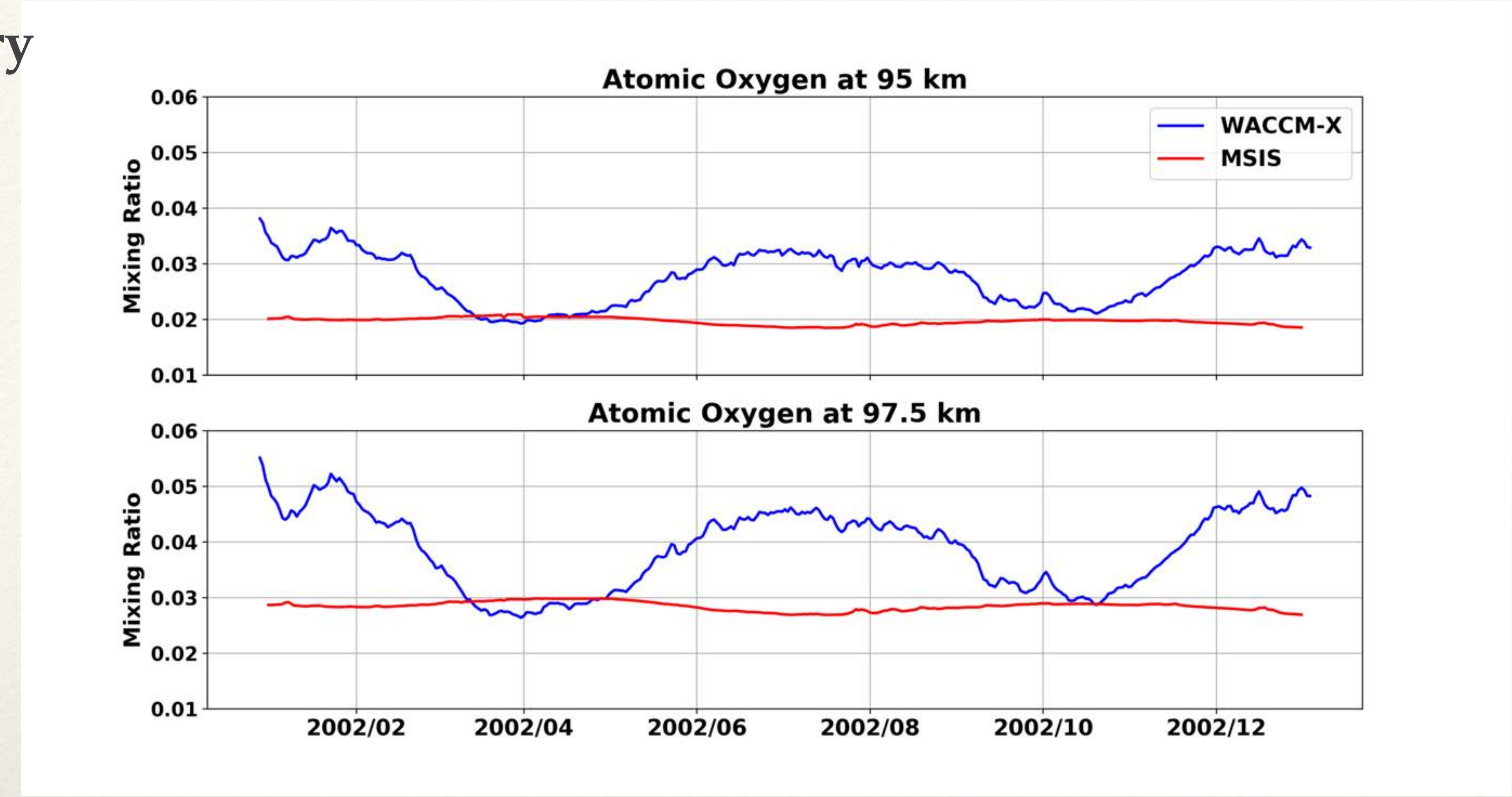
a) Lower boundary of GITM is incorrect.

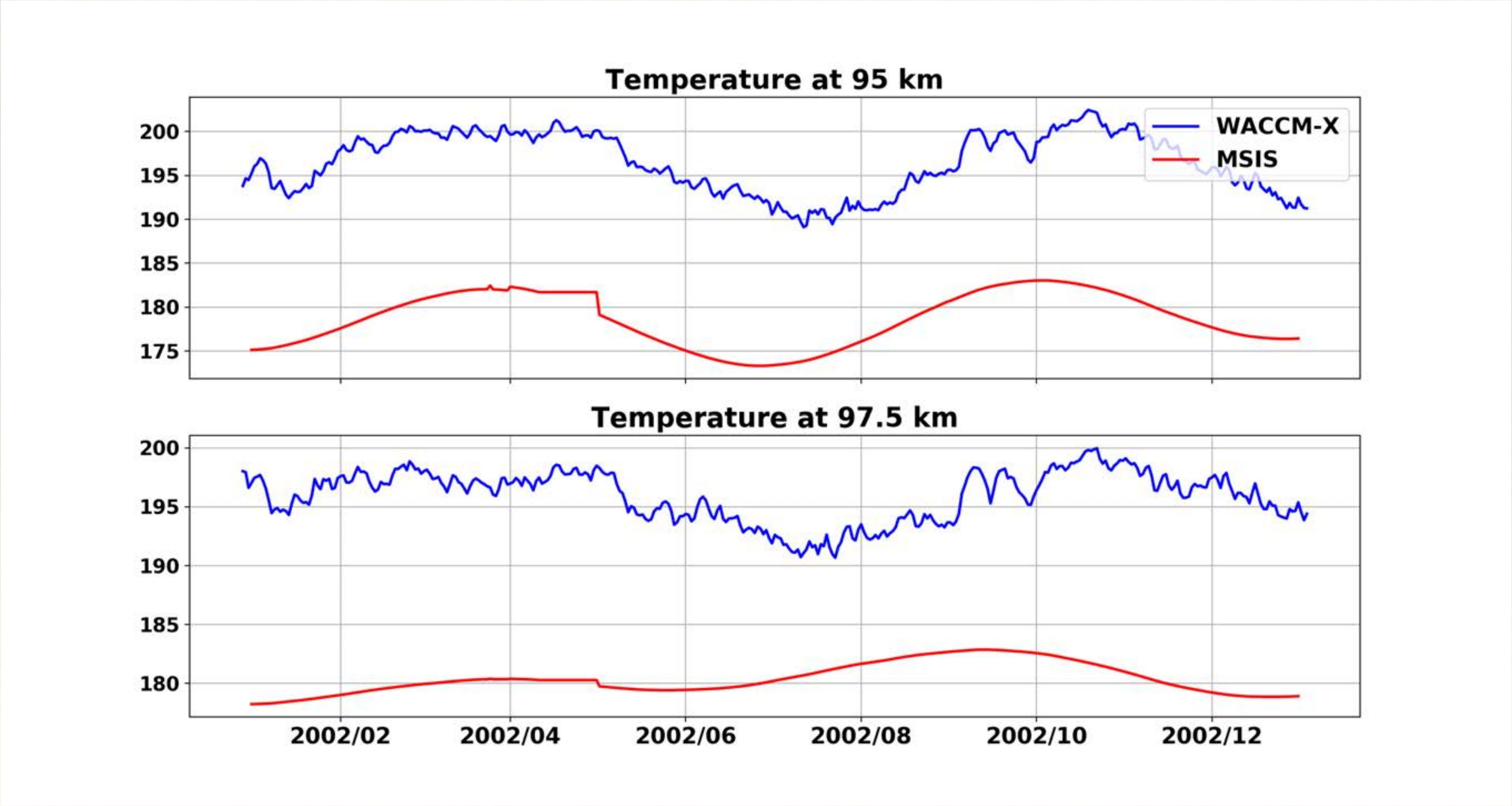
b) Eddy diffusion coefficient in GITM is incorrect.

Investigating Lower Boundary

Can we use WACCM-X ?

At the lower boundary, MSIS vs WACCM-X





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Global Ionosphere Thermosphere Model

- First-principles model that simulate the thermosphere and ionosphere by solving for density, momentum and energy self-consistently. [Ridley et al., 2006]
- GITM uses a 3-D spherical grid that can be stretched in both latitude and altitude.
- Uses an altitude-based grid and does not assume a hydrostatic solution
- Can be run in 1D or 3D modes.
- Allows different models of high latitude electric fields, auroral particle precipitation, solar EUV inputs, particle energy deposition
- The magnetic field can be represented by either ideal dipole magnetic field or a realistic APEX magnetic field.
- Initial state can be set either by MSIS/IRI, user inputs or from a previous run.
- MSIS is an empirical model that relates the neutral densities and temperature to the integrated solar flux approximation (F10.7) and activity level (Ap). It is a spherical harmonic fit to many different satellite and remote observations.
- Solves explicitly for O, O_2, N(^{2}D), N(^{2}P), N(^{4}S), N_2, NO, H, He and ion species $O^+(^4S)$, $O^+(^2D)$, $O^+(^2P)$, O_2^+, N^+, N_2^+, NO^+, H^+, He^+

Whole Atmosphere Community Climate Model

- WACCM-X : Thermosphere and Ionosphere extension to WACCM (~upto 130 km) with model top boundary between 500-700 km.
- Built upon Community Atmosphere Model (CAM) which that goes upto ~40 km.
- Has the option to constrain the tropospheric and stratospheric by reanalysis toward MERRA - 'Specified dynamics'.
- Resolution : 1.9 degree in latitude and 2.5 degree in longitude.
- Vertical resolution of 1/4 scale height above 1 hPa, with 125 vertical levels.
- Gravity wave parameterization : Linear saturation theory (Lindzen 1981)
- The chemistry module is interactive with the dynamics through transport and exothermic heating - derived from a 3D model MOZART.
- Production and loss of electrons and 5 ions - O^+, O_2^+, NO^+, N^+, N_2^+
- Heating due to energetic photoelectrons calculated using Solomon and Qian [2005]

Simulations

- GITM Resolution : 2 degrees Latitude and 4 degrees Longitude
- Vertical resolution : <3 km in the lower thermosphere and. >10 km in the upper thermosphere (1/3rd of the scale height)

  Model Inputs :
- Lower Boundary : MSIS, HWM or WACCM-X.
- High Latitude Potential: Weimer05 [Weimer 1995]
- Auroral Power : Hemispheric Power Index from NOAA (uses POES and Fuller Rowell Evans [1987])
- Solar wind data : ACE (Advanced Composition Explorer Satellite) [Chamberlin et al. 2007]
- Solar EUV Flux : FISM (Flare Irradiance Spectral Model)

We couple GITM with WACCM -X at the lower boundary and compare it with the default MSIS driven GITM. O, O_2, N_2, N, NO, T, U, V are coupled.

Table 2. Geomagnetic Conditions

Time Period (2002)	Max F10.7	Min Dst (nT)
5-8th Jan	205.2	-25
6-9th April	208.4	-12
22-24th June	155.3	-23
23-25th September	158.9	-25

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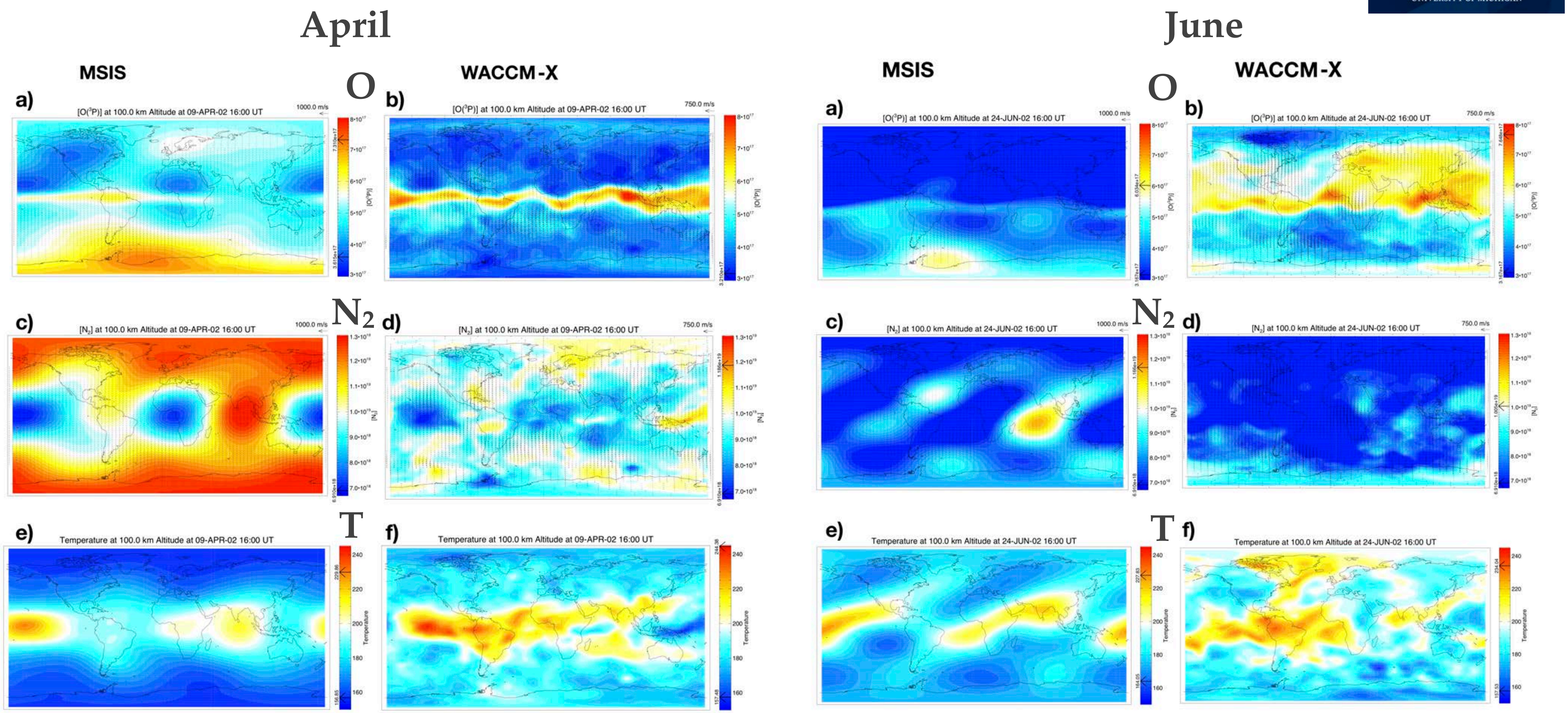
- **RESULTS**
- SUMMARY

Results

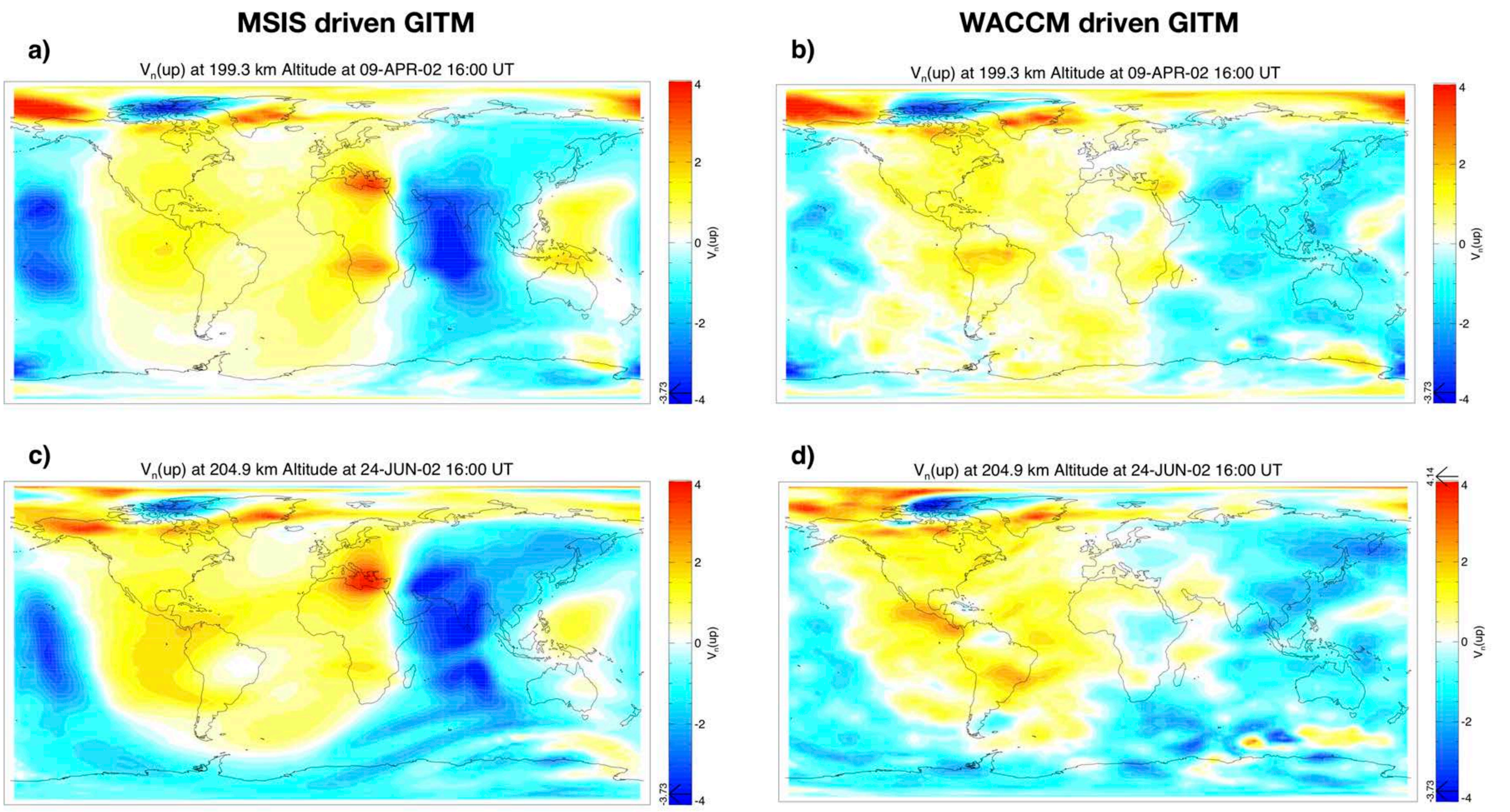


- WACCM-X has smaller tidal amplitudes as compared to MSIS - gravity wave parameterization
- Larger Temperatures.
- Smaller scale variabilities in WACCM-X.
- Excessive dissipative heating from gravity wave parameterization might be responsible for smaller tidal amplitudes, excessive heating. [Liu et al., 2010]

Results : Vertical Velocity

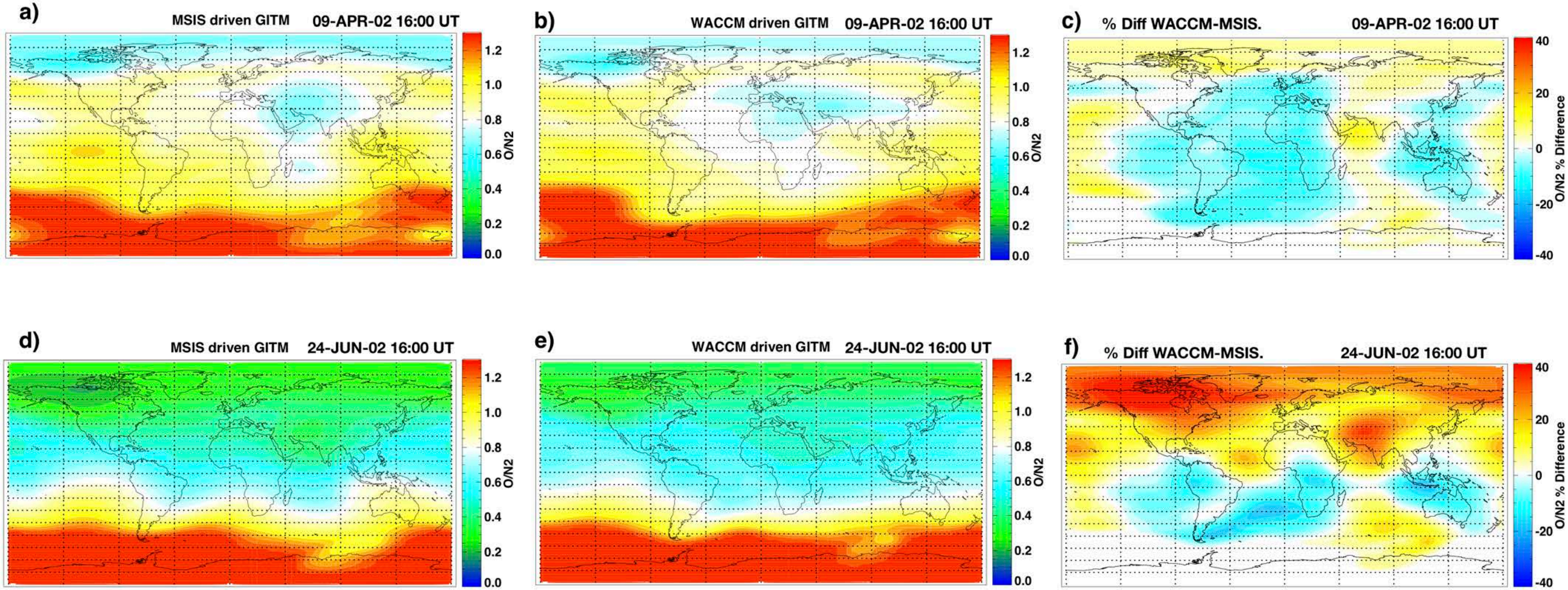
April

June



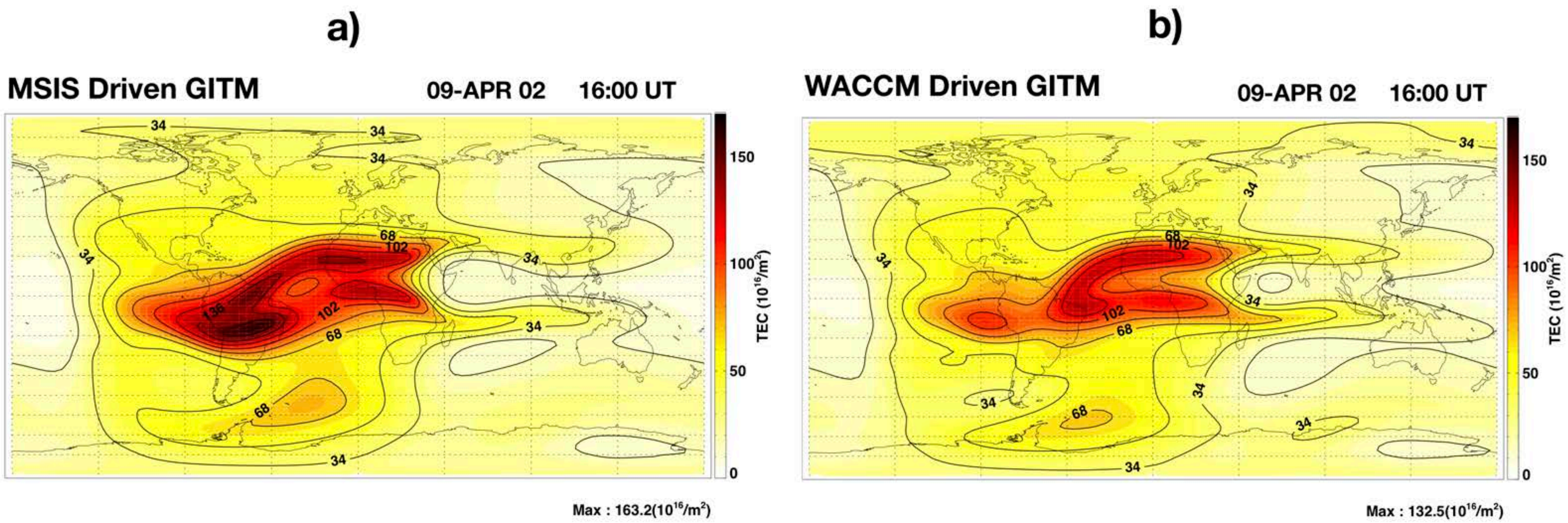
- The vertical velocity for MSIS also shows a tidal structure which is missing from WACCM-X.

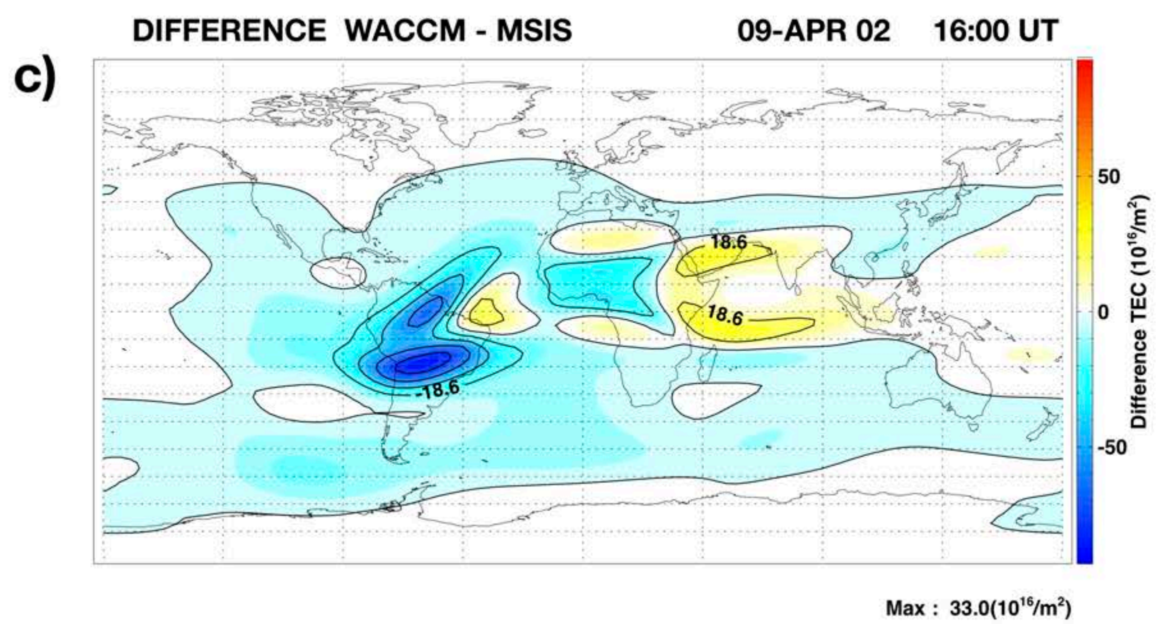
Results : O/N_2



- At southern polar latitudes, WACCM-X and MSIS driven runs match well
- The tidal structures from MSIS maps into the upper thermosphere.

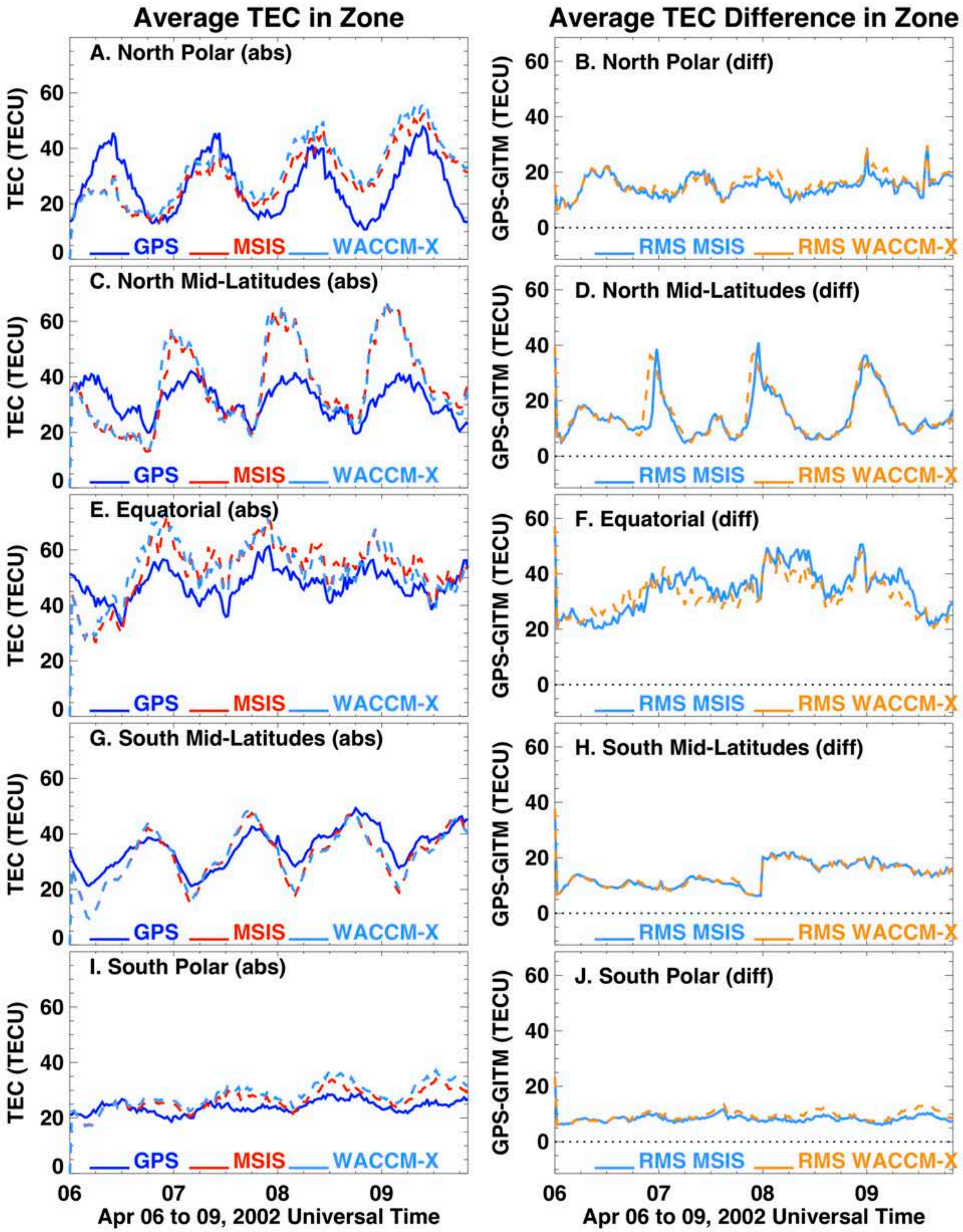
Results : Total Electron Content

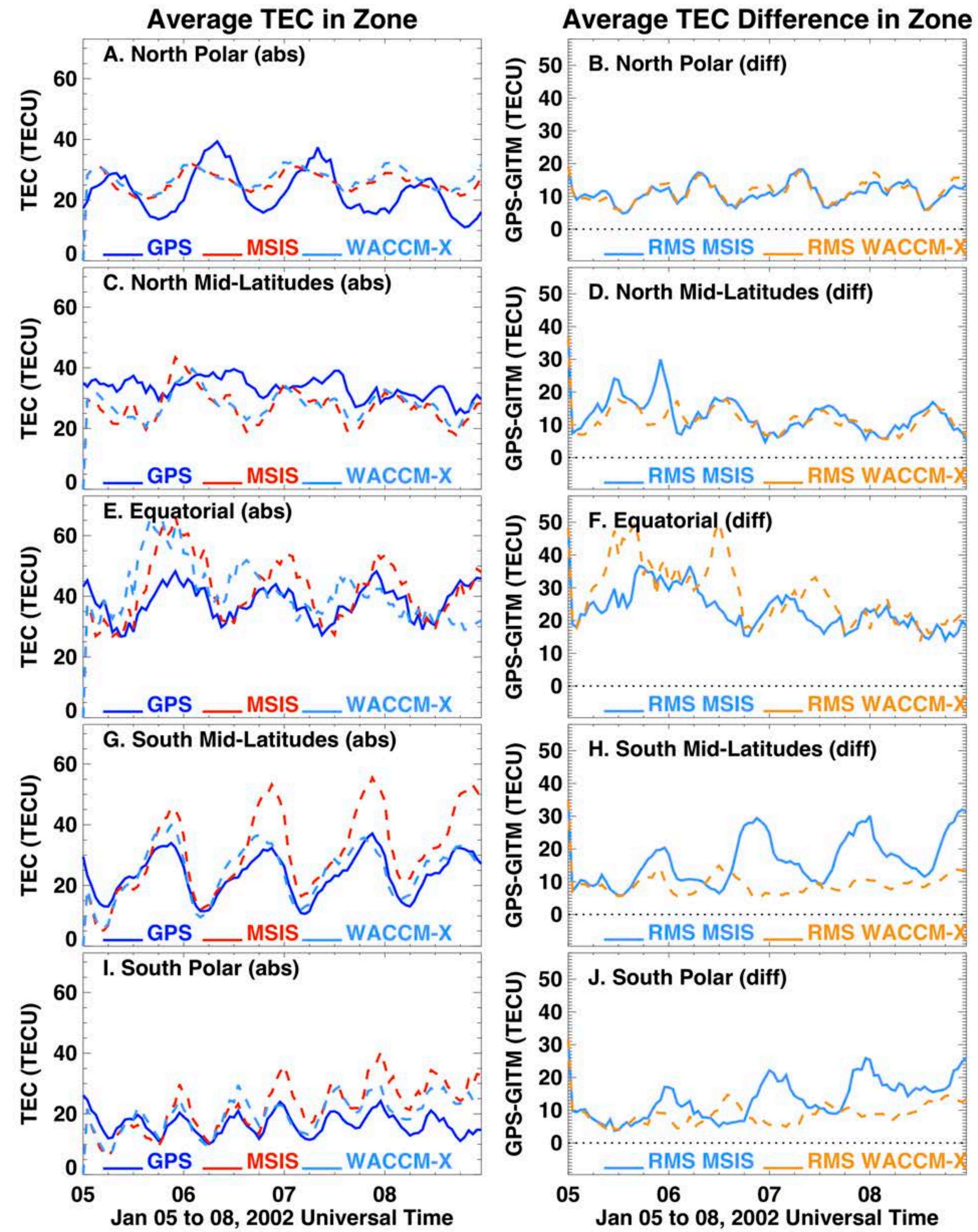




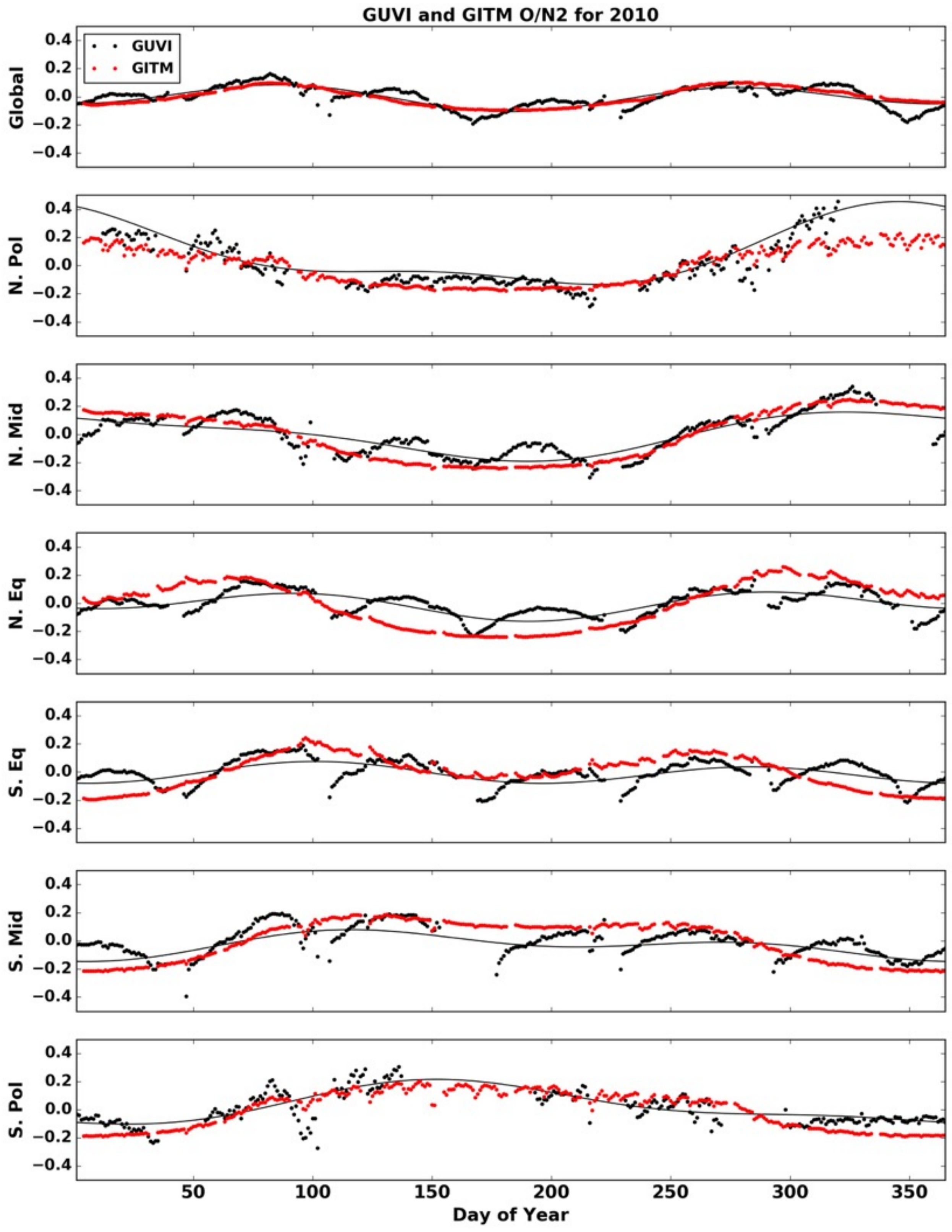
- The TEC between the two simulations is matches well at high latitudes.
- The difference between EIA of the two simulations tells us about the influence of tides on the TEC.

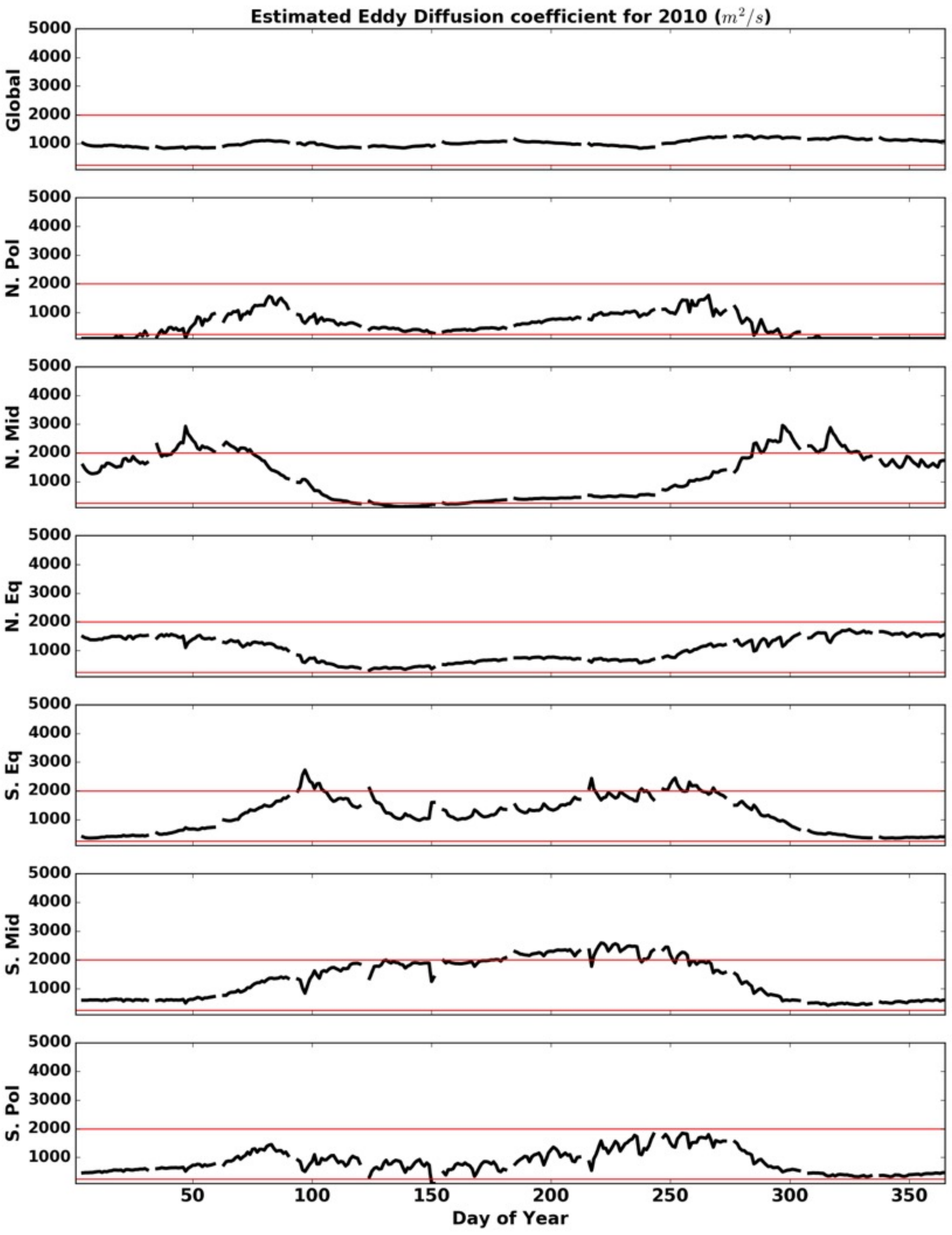
MSIS driven vs WACCM-X driven GITM vs GPS TEC



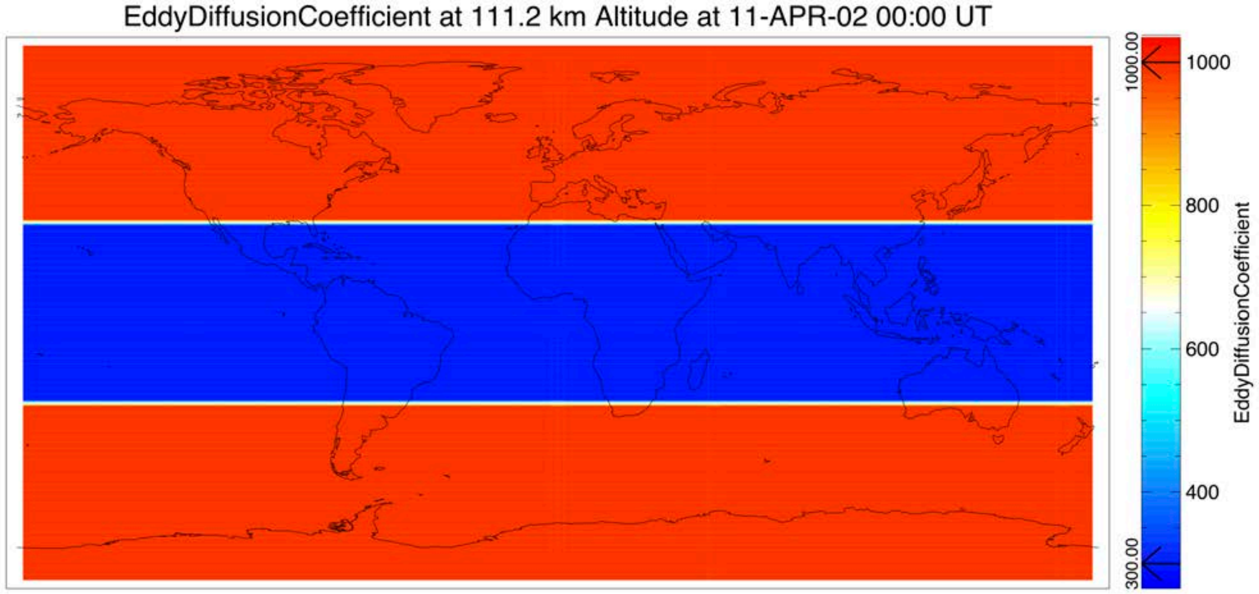


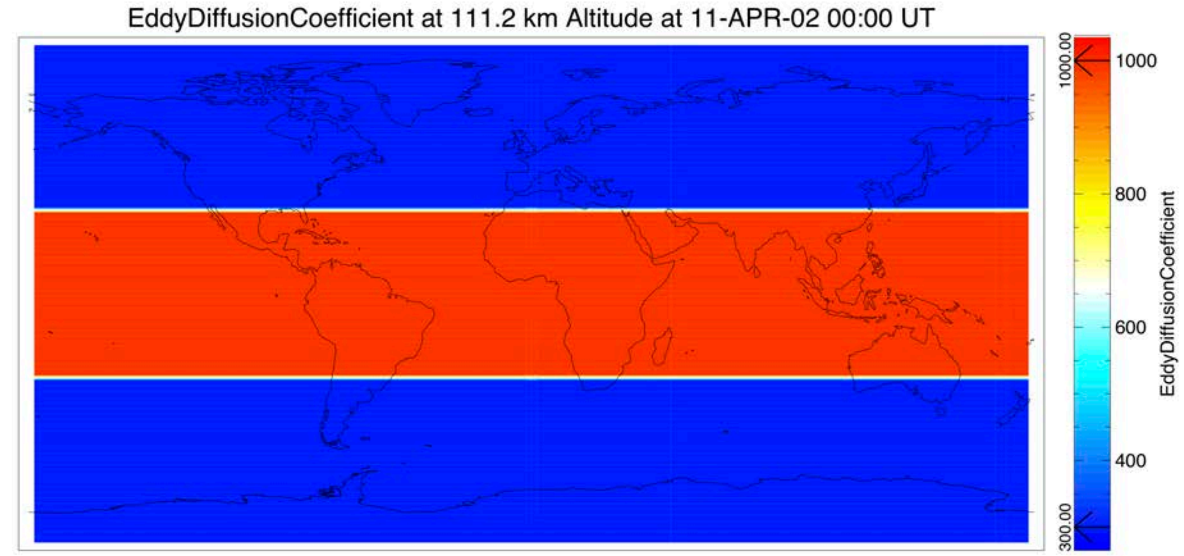
Sensitivity studies for K_{zz}



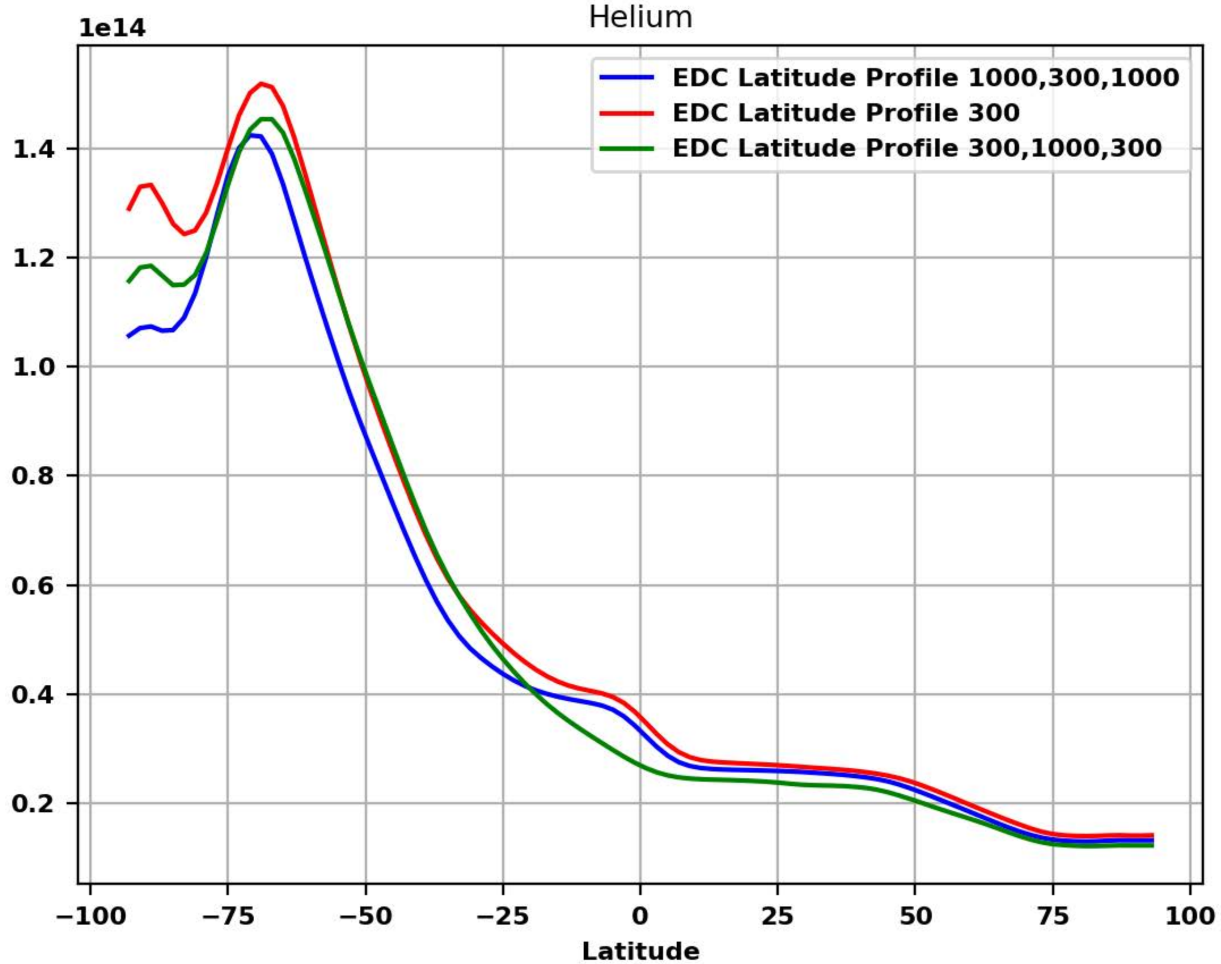


Latitudinal profile in K_{zz}

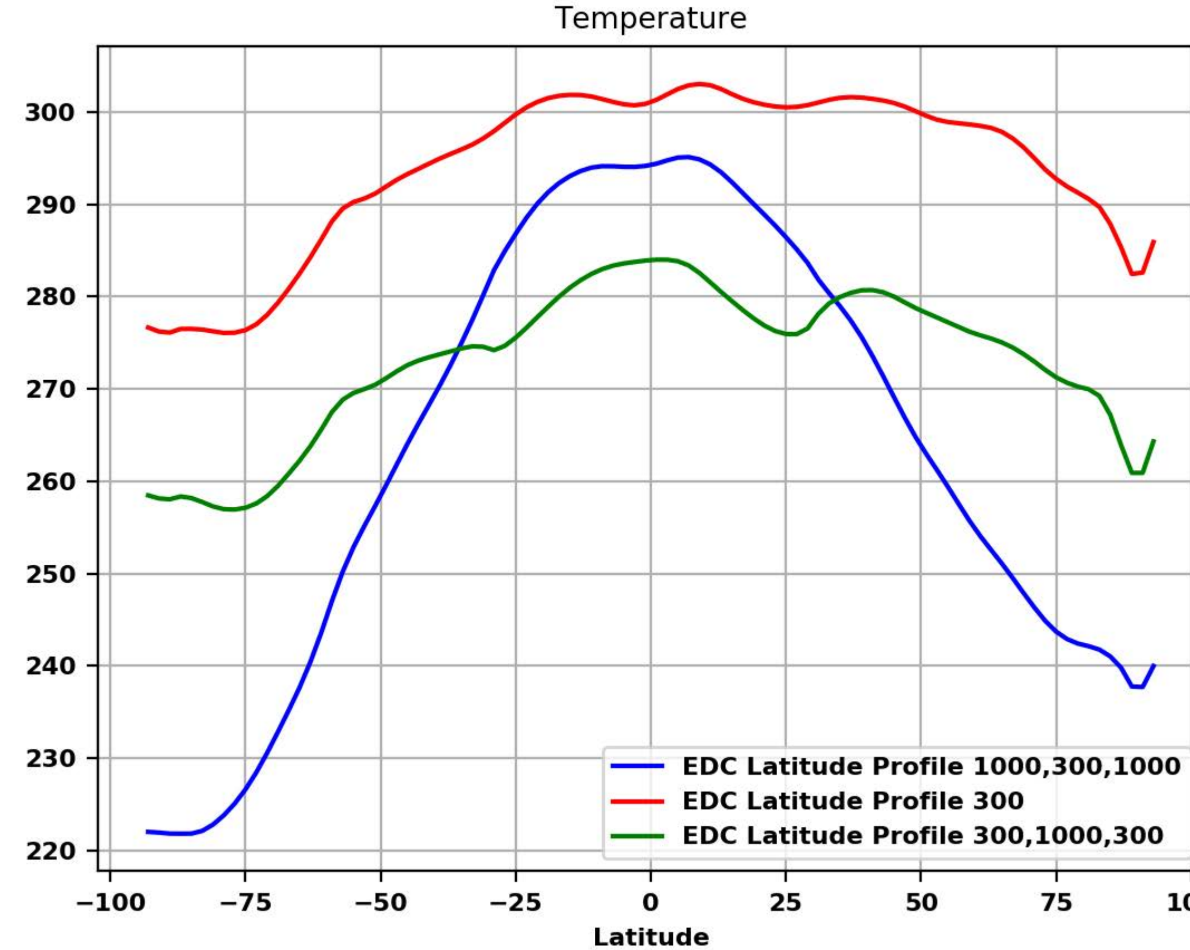




113.4 km



He



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- **SUMMARY**

Summary

- The lower boundary does have a substantial effect on the IT system.
- When using MSIS vs WACCM-X lower boundary, we find the highest change during solstices and at lower latitudes.
- This change in the lower boundary might not be enough to solve the discrepancies with observations in GPS TEC observations and neutral densities.
- However, comparison of MSIS and WACCM-X atomic oxygen at the lower boundary of GITM does indicate that the thermospheric semi-annual oscillation most probably has its source in the lower atmosphere.
- We are also performing sensitivity analysis to understand the effect of eddy diffusion on the thermosphere. The temperature shows a larger sensitivity than the mixing and this needs to be investigated further.

References

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2006, Pages 839-864, ISSN 1364-6826, https://doi.org/10.1016/j.jastp.2006.01.008. (http://www.sciencedirect.com/science/article/pii/S1364682606000071) Keywords: Thermosphere; Ionosphere; Modeling; Global circulation models

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